System Engineering and Spacecraft

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The System Engineering Approach

- The goal of System Engineering is to develop a set of uniform procedures which effectively apply good engineering practice to large, complicated, or costly systems. The object is to meet needed requirements subject to minimizing cost with a controlled level of risk.
- Design proceeds from the top down
- Higher level requirements drive design at lower levels
- But process is highly iterative; results of analysis at lower levels can force changes at higher levels
- Typically involves multiple trade studies
- Encompasses all design and engineering on the program
- Process was begun by the entire science community before SNAP was a project

System Engineering Applied to SNAP

- **Baseline Science**
  - — **Want to measure W_{M}, W_{I}, and dark energy**
  - — **Results from discussions and interaction with the entire science community**
- **Science Approach**
  - — **Use Standard Candle method to examine 2000 supernova of type Ia**
  - — **Measure magnitude and redshift to a few percent accuracy**
  - — **Process is lead by SNAP science team with input from entire community**
  - — **Subject to trades and wholesale revision of approach**
  - — **A key conclusion at this level is that SNAP cannot be done from the ground, but requires a space based telescope**
- **Instrumentation Approach**
  - — **Derive requirements on FOV**
  - — **Aperture and time on target**
  - — **Resolution, and pointing**
  - — **Instrument complement**
  - — **Data volume and return**
  - — **Trades at this level are still best made by scientists. Should maximize exposure and number of scientists involved in early planning.**

System Engineering Applied to SNAP

- **Mission Design**
  - — Model observatory size and mass by scaling similar programs
  - — Make estimates of instrument requirements
  - — Do orbit trade studies and estimate launch vehicle requirements
  - — Make trade studies of down link options
  - — Develop preliminary requirements on spacecraft
  - — Activity at this point is still being lead by the science team, but with increasing engineering input

- **Observatory Design**
  - — This activity is lead by engineering staff
  - — The process starts with a review of the science requirements
    - Pointing
    - FOV, Aperture
    - Resolution
    - Instruments size, mass, power, and data requirements
  - — Then a first set of derived requirements are developed
    - E.g. requirements on the spacecraft

System Engineering Applied to SNAP

— Finally a design approach is developed for the observatory
- Process starts with developing a design for the Optical Telescope Assembly
- OTA sensitivity calculations drive requirements on the structure and thermal systems
- A preliminary instrument layout is made
- Structure design approach
- Mirror fabrication approach
- Thermal requirements and thermal control system design
- Testability requirements are developed
- Interface Control Documents are prepared and maintained
  - —Mechanical, Optical, Thermal, Electrical
- Preliminary specifications on spacecraft systems are developed
- Spacecraft structure is refined
- Instrument designs and requirements are refined
- Requirements on the data system are developed
- Data system is laid out and refined

Status of the Observatory / Mission Design

- **Orbit trade study completed**
  - — **"Prometheus" orbit selected**
  - — **Analysis shows a Delta III or IV-M can place 2800 kg. in this orbit**
- **Preliminary Size, Mass, and Power developed**
- **Preliminary layout of observatory structure generated**
- **Extensive trade studies of alternative OTA designs done**
- **Design and trade studies of the instrument complement**
- **Result of LOI is to get estimates from industry of the spacecraft cost**
- **Strawman spacecraft was presented at the last review**

Orbit Trade-Study

Feasibility & Trade-Study

Orbit	Radiation	Thermal	Telemetry	Launch	Stray Light	Rank
HEO/ Prometheus	Very Good	Passive	Med. BW	Fair	Dark	1
HEO / L2	Very Good	Passive	Low BW	Fair	Dark	2
HEO / GEO	Poor	Passive	24 hr	Fair	Dark	3
LEO / Equator	Lowest Dose	Mechanical	High BW	Fair	Earth Shine	4
LEO / Polar	High at Poles	Mechanical	High BW	Excellent	Earth Shine	5
LEO / 28.5	Lowest Dose	Mechanical	High BW	Excellent	Earth Shine	6

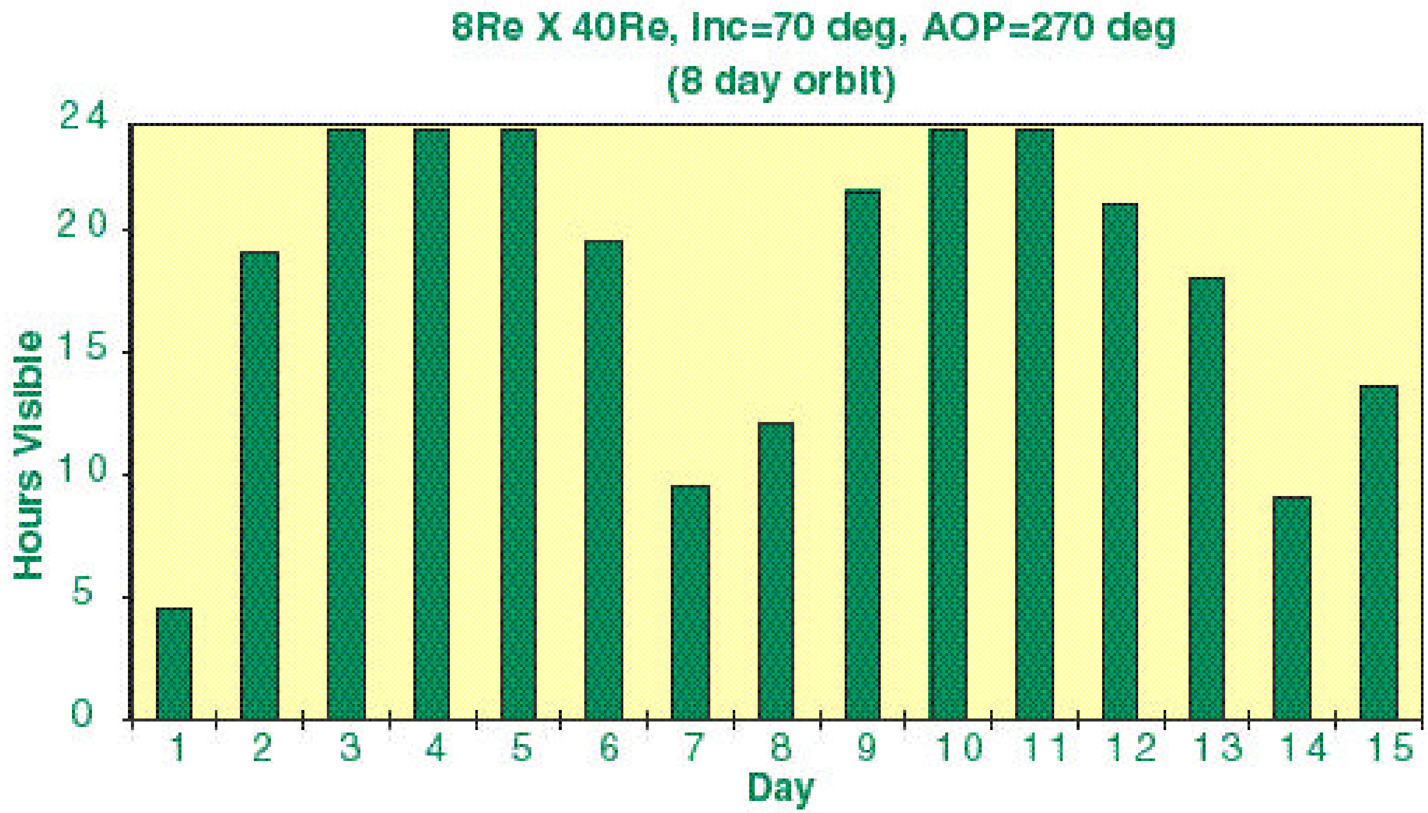
Selected Lunar Assist "Prometheus" Orbit

14 day orbit: 19Re Perigee/57Re Apogee

7 day orbit: 8Re Perigee/40Re Apogee

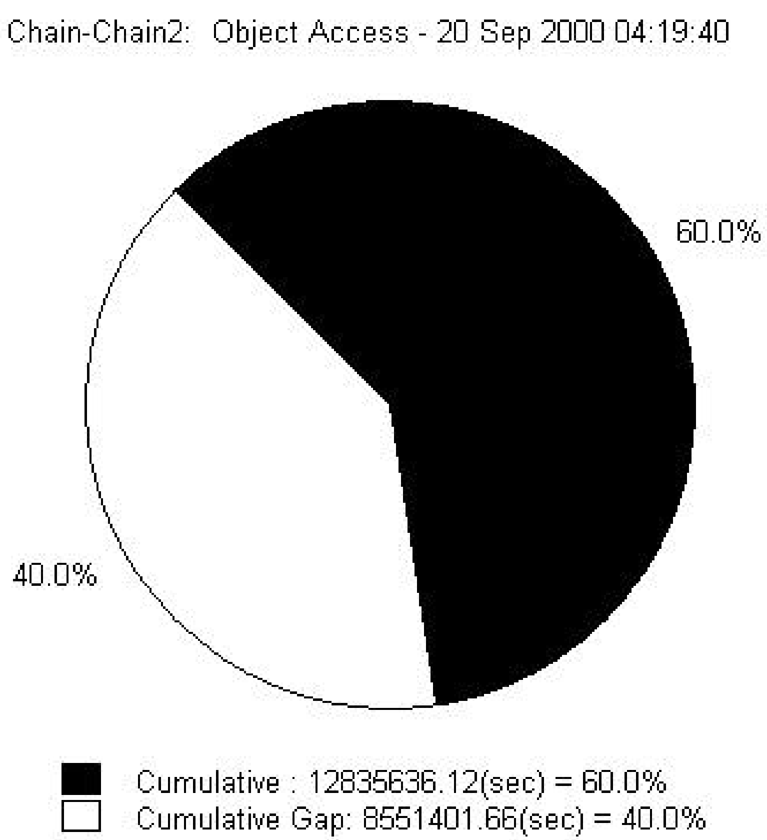
Telemetry for Prometheus Orbit

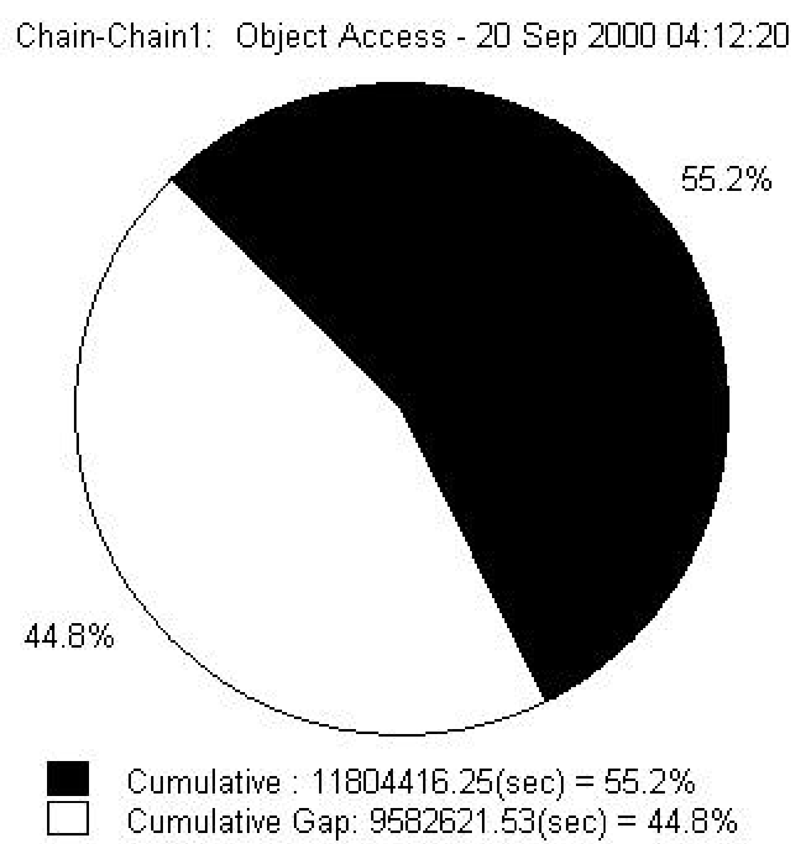
- High northern hemisphere orbit has excellent telemetry: ~50 Mbit/s for 19/57 orbit, >50 Mbit/s for 8/40 orbit
- 8 Gbit image every 200s + 40 Mbit/s (2:1 compression, no image stacking required)
- Data content is approx. 1/3 optical images, 1/3 spectroscopy, 1/3 IR photometry



Coverage Time

- **Over the course of the three year lifetime**
  - **— 60% is spent in Northern Hemisphere**
  - **— 55.2% is spent in LOS contact with Bay Area**



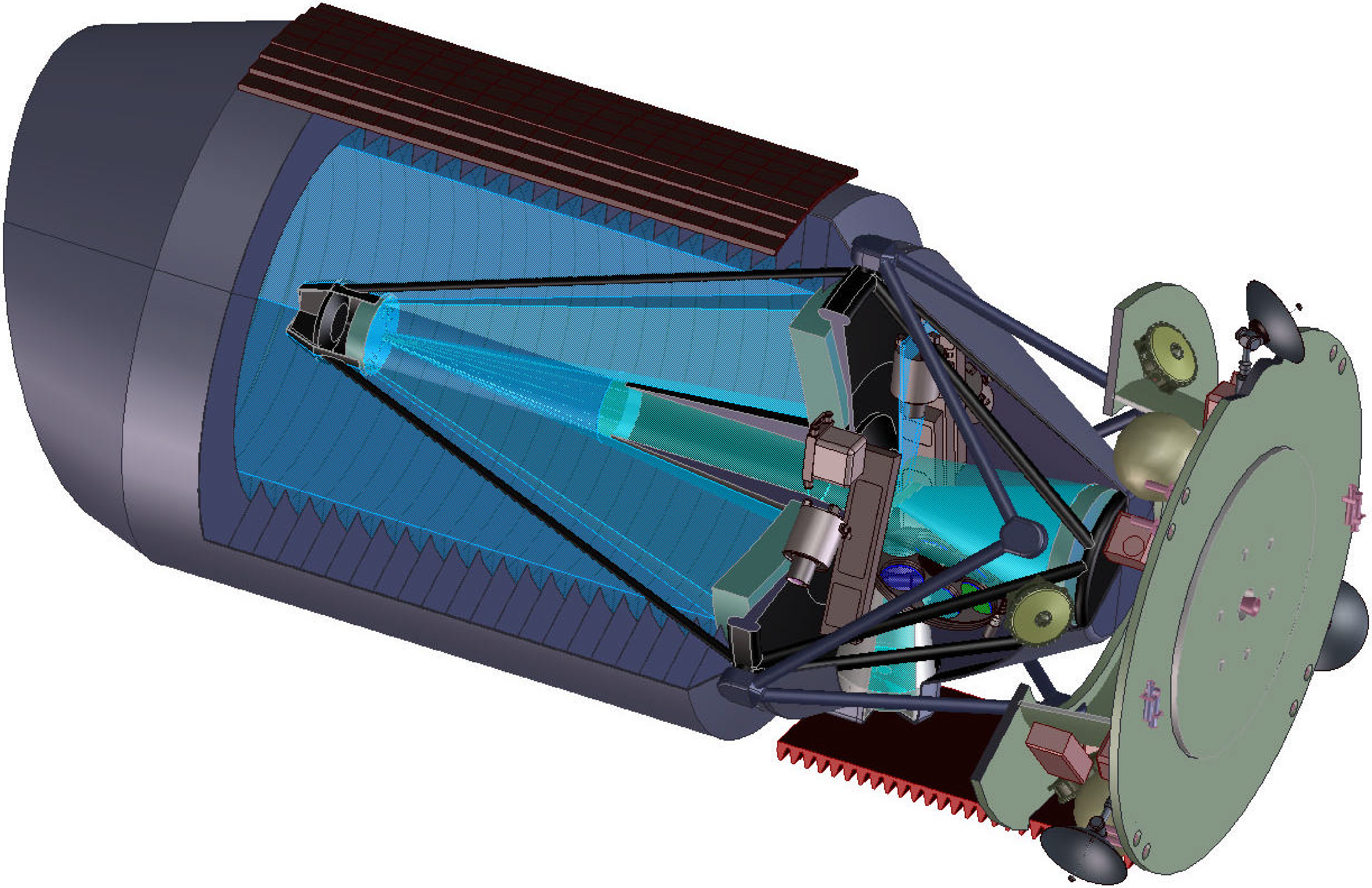


Spacecraft and Launch Vehicle

- **Spacecraft Bus**
  - **Pair with industry**

- **Launch**
  - **Delta IV-M launch vehicle provides 2800 kg lift to our orbit**
  - **Early estimated weight of SNAP is 1800 kg**

Cut away View of Structure



Mission Operations

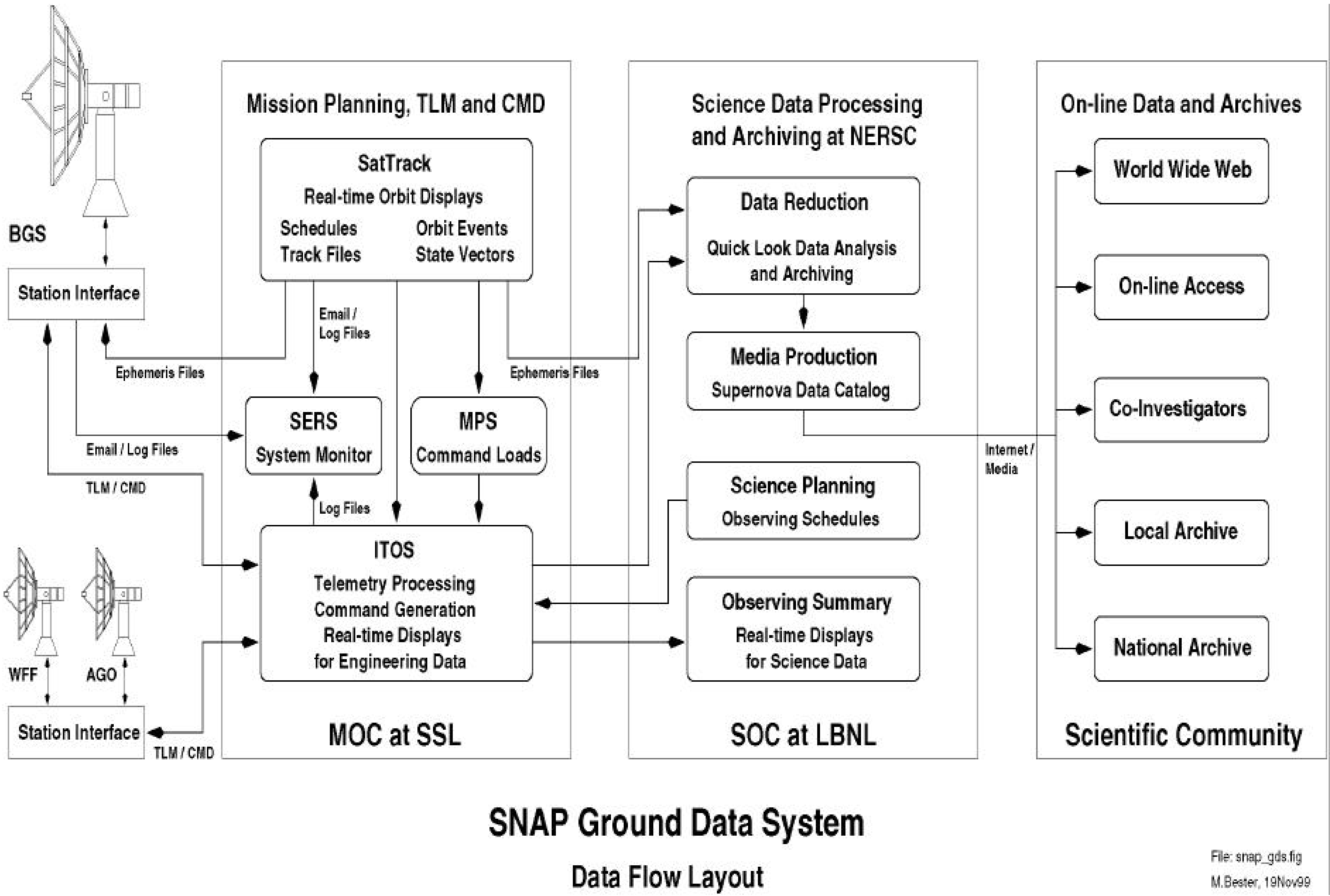
Mission Operations Center (MOC) at Space Sciences Using Berkeley Ground Station

- **Fully Automated System Tracks Multiple Spacecraft**
    - **11 meter dish at Space Sciences Laboratory in operation for one year**
- **Science Operations Center (SOC) at Lawrence Berkeley Laboratory Built Around the National Energy Research Super Computer (NERSC)**
- **Multiple Terabytes Data Storage**
- **High Speed Links to CPU Farms & Supercomputers**
- **Intensive Processing Done on Supercomputers**

Operations are Based on a Four Day Period

- **Autonomous Operation of the Spacecraft**
- **Coincident Science Operations Center Review of Data with Build of Target List**
- **Upload Instrument Configuration for Next Period**

SNAP Ground Data System



Activities Planned for Conceptual Design Phase

- Optical Telescope Assembly optics design, trade studies, risk assessment and ICD's
- Instrument development
- Orbit analysis and study
- Structure design
- Thermal control system design
- Attitude Control System analysis and modeling
- Spacecraft systems refinement
- Integration and Test planning
- Launch vehicle selection and feasibility study
- Data system layout
- Reliability Analysis and redundancy study

Optical Telescope Assembly System

- **OTA requirements development is well under way and will be continued during the Conceptual Design Phase**
- **Given the highly specialized skills involved, the detailed design and fabrication of the OTA will be done by an outside optics contractor**
- **Since design of the OTA is the starting point for the design of the entire observatory, and the procurement is a very long-lead activity, this will be a key development task during the Conceptual Design Phase**

Instrument Systems

- Instrument system requirements have been the the focus of substantial study during the pre-concept period which will continue during the Conceptual Design Phase

- A number of technology development areas have been identified which will be discussed in detail in later presentations

Orbit Analysis and Modeling

- Orbit choice strongly impacts mission design
  - Eclipse time
  - Telemetry options
  - Thermal drivers
- “Prometheus” orbit first identified in NASA Goddard study
- Uses energy from moon to raise perigee
- Requires small hydrazine system on spacecraft to lower apogee
- Similar maneuvers are routinely done on interplanetary programs
- We will contract with a navigation group to do a detailed analysis to the orbit and to develop a navigation plan
- This will define requirements on
  - Launch vehicle
  - Propulsion system
  - Attitude Control System
  - Command and data system

Observatory Structure Design

- The structure drives every aspect of the observatory, particularly
  - Thermal control
  - Attitude Control
  - Testing and Integration
- Project team will develop and refine a detailed structure layout
- This will be used to generate a mechanical math model to support ACS as well as thermal and structural analysis

Observatory Thermal Control

- Heavily interacts with the structure and stray light baffling
- Strong thermal requirements on the OTA and instruments must be addressed
- Needed thermal baffles and structure may adversely affect ACS
- The thermal control task will include a preliminary layout and strategy for thermal control of the solar array
- This task is closely tied to every aspect of the observatory development, and is therefore a high priority

Attitude Control System Design and Modeling

- **Control to better than the .03 arc-sec, 3 sigma SNAP requirement has been done on other spacecraft with more challenging structural properties (e.g. .005 arc-sec on Hubble)**

- **The ACS system interacts strongly with many other observatory systems**
  - **Structure**
  - **Thermal control**
  - **OTA (Tracker data from the OTA is needed by the ACS for fine attitude control, and reaction wheel rumble from the ACS may degrade OTA performance)**
  - **Navigation and orbit insertion**

- **Project will contract with an aerospace contractor to refine the ACS system design and construct a computer model of the system**

- **This will be maintained and updated thoughout the observatory development process**

Spacecraft Systems

- A refined set of requirements on the spacecraft will be developed and documented during the Conceptual Design Phase
- The SNAP project plans to team with an aerospace industrial partner who will develop and supply the spacecraft portion of the observatory
- Since the observatory design is so strongly driven by the payload, we believe that costs will be minimized by refining the payload design before bringing the teaming partner on board
- The S/C strawman will be updated and refined as new data and requirements are developed from the structural, thermal, ACS, and navigation studies done during the Conceptual Design Phase
- We plan to issue an RFP and select a partner by the end of Phase B

Integration and Test Planning

- This activity will be lead by the OTA development team because the main driver for the task is the testing of the telescope and metering structure
- The plan is built around mirror and telescope test procedures
- The activity is then expanded to include all tests of the observatory and the instruments including environmental testing and calibration
- A key output of this task is the development of requirements and a plan to acquire necessary facilities and equipment

Command and Data System Layout and Redundancy Trade Studies

- As a part of the Conceptual Design Phase instrument development activities, data requirements from the instruments will be refined
- This will enable a refined layout of the data system to be done
- We will evaluate distributed vs. centralized architectures
- Different levels of functional and block redundancy will be evaluated and a policy regarding single point failures and redundancy will be developed